Science Data Validation Plan

*MODIS Atmospheres Group**

1.0 Introduction

1.1 Scientific Objectives

We intend to collect a well-calibrated data set of high spectral and spatial resolution measurements to support radiometric calibration of the MODIS shortwave and longwave channels and the development of the following MODIS atmosphere algorithms:

- Cloud mask for distinguishing clear sky from clouds;
- Cloud radiative and microphysical properties (cloud top pressure and temperature, effective emissivity, cloud optical thickness, thermodynamic phase, and effective radius);
- Tropospheric aerosol optical thickness over the land and ocean and aerosol size distribution over the ocean;
- Column water vapor amount;
- Atmospheric profiles of moisture and temperature;
- Fire detection, emitted thermal energy and ratio of consumption in the smoldering and flaming stages. This product is produced in collaboration with the land group.

A summary of these algorithms can be found in King et al. (1992), as well as in detailed descriptions of each algorithm, to be found in Algorithm Theoretical Basis Documents (ATBDs) available through World Wide Web (http://spso.gsfc.nasa.gov/spso_homepage.html).

1.2 Missions

MODIS will be carried onboard the first EOS spacecraft, designated AM-1, to be launched in June 1998. In addition to AM-1, MODIS will fly aboard PM-1 in December 2000. These two spacecraft will likely be repeated in the morning

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and afternoon orbits with advanced versions of MODIS, providing a data set similar to MODIS from 1998-2018. In order to validate the MODIS-derived atmospheric products to be derived from these data, it is necessary to validate specific geophysical parameters under a wide variety of atmospheric conditions from arctic stratus clouds in the summertime arctic, multi-layer cloud systems in the polar night, convective cloud systems in the intertropical convergence zone, and aerosol properties over the ocean and several land surface covers.

Several field programs offer opportunities for pre-launch and post-launch MODIS validation through collection and analysis of observations obtained from the MODIS Airborne Simulator (MAS; King et al. 1996) and High-spectral resolution Interferometer Sounder (HIS; Revercomb et al. 1988). These field campaigns, principal focus, and MODIS atmosphere group participants, include:

Mission	***Dates***	***Responsible Team Members***	***Primary Purpose***
SUCCESS	April-May 1996	Steve Ackerman, Si-Chee Tsay, Steve Platnick	cirrus cloud properties
TARFOX	July 1996	Didier Tanré, Yoram Kaufman	tropospheric aerosol and cirrus over the ocean
FIRE III	April-June 1998 Aug-Sep 1998	Michael King, Si-Chee Tsay	arctic stratus clouds over sea ice
LBA	September 1999	Bo-Cai Gao, Paul Menzel, Michael King, Si-Chee Tsay	tropical clouds and biomass burning
MODIS-specific validation campaigns			
WINCE	February 1997	Paul Menzel, Steve Ackerman, Dorothy Hall	cloud detection and properties over snow/ice covered surfaces
ARM-1	September 1998	Paul Menzel, Steve Ackerman	periodic flights over the Oklahoma ARM site with MAS & HIS
ARM-2	April-May 1998	Paul Menzel, Steve Ackerman	periodic flights over the Oklahoma ARM site with MAS & HIS

Mission	Dates	Responsible Team Members	Primary Purpose
MOBY	December 1998	Paul Menzel, Steve Ackerman	cirrus clouds and atmospheric corrections over the ocean
California	July 1999 December 1999	Michael King, Steve Platnick, Si-Chee Tsay	marine stratocumulus and valley fog
Mid-Atlantic	August 1999	Yoram Kaufman, Didier Tanré, Lorraine Remer	aerosol optical thickness and size distribution, water vapor
Gulf of Mexico	January 2000	Paul Menzel, Chris Moeller	clear sky and cirrus clouds, including sediment outflow from river estuaries
California & Pacific Northwest	September 2000	Yoram Kaufman, Lorraine Remer, Elaine Prins, Didier Tanré	fire detection and smoke aerosol properties

In addition to these ER-2 field campaigns, which often include the Cloud Lidar System (CLS; Spinhirne et al. 1989) for verifying cloud top altitude and multi-layer clouds, the University of Washington CV-580, with the Cloud Absorption Radiometer (CAR; King et al. 1986) and extensive in situ cloud microphysics (liquid water content, effective radius, cloud drop size distribution), aerosol properties (size distribution, scattering and absorption coefficients), and meteorological sensors, will be used as required.

In addition to these airborne campaigns in which MODIS team members are directly planning to participate, we expect to make use of selected ground-based networks as follows:

Measurement	Location	Responsible Team Members	Primary Purpose
AERONET	multiple locations in US, Japan, South America, Africa, & Europe	Brent Holben, Yoram Kaufman, Didier Tanré	aerosol optical thickness and columnar size distribution

Measurement	***Location***	***Responsible Team Members***	***Primary Purpose***
ARM	Oklahoma, North Slope of Alaska, Western Tropical Pacific	Paul Menzel, Si-Chee Tsay	cloud base height (micropulse lidar), temperature and moisture profiles, sky radiance (visible and IR)
AEROCE	multiple island locations worldwide	Joe Prospero, Yoram Kaufman, Didier Tanré	aerosol hydroscopicity, scattering and absorption coefficients, size dependent chemical composition

The ground-based measurements will be obtained on a continuous basis as well as during intensive field experiments. All of these validation opportunities, as well as intercomparison of data derived from MODIS with other sensors on AM-1 and other spacecraft, will be discussed in detail below.

1.3 Science Data Products

The MODIS atmosphere validation plan addresses the MODIS cloud mask as well as investigator science products characterizing cloud top properties, cloud radiative and microphysical properties, aerosol optical thickness and (over the ocean) aerosol size distribution, precipitable water vapor over the land and ocean glint regions, fires, and atmospheric profiles of moisture and temperature. Validation of the shortwave and longwave radiances, developed as part of the MODIS validation plan, will also be assessed and discussed in this validation plan.

2.0 Validation Criteria

2.1 Overall Approach

Validation will be approached in several ways: (i) collocation with higher resolution aircraft data, (ii) ground-based and aircraft in situ observations, and (iii) intercomparisons with other AM-1 platform instruments. Our validation approach relies heavily on the sources of the data that were used in the algorithm development, which consisted primarily of the MAS, a fifty channel visible, near-infrared, and thermal infrared imaging spectrometer with 50 m resolution at nadir (King et al. 1996), HIS, a 2 km resolution nadir-viewing Michelson interferometer with 0.5 cm^{-1} spectral resolution from 4 to 15 m m (Revercomb et al. 1988), and AVIRIS, a 224 band imaging spectrometer from 0.4-2.5 mm with 20 m resolution at nadir (Vane et al. 1993). In addition, we plan to make extensive use of the AERONET (Aerosol Robotic Network), a network of ground-based sunphotometers established and maintained by

Brent Holben that measures the spectral aerosol optical thickness and sky radiance, reporting the data via a satellite communication link from each remotely-located CIMEL sunphotometer to Goddard Space Flight Center from sunrise to sunset, 7 days a week. Finally, we plan to utilize ground-based microwave radiometer observations to derive column water vapor, especially over the Atmospheric Radiation Measurement (ARM) CART (Clouds And Radiation Testbed) site in Oklahoma.

Well-calibrated radiances are essential for the development of accurate algorithms. The calibration of the HIS is such that it serves as a reference for line-by-line radiative transfer models. The MAS infrared channels are calibrated through two onboard blackbody sources that are viewed once every scan, taking into account the spectral emissivity of the blackbodies. Calibration of the shortwave infrared and thermal infrared channels will be routinely assessed through vicarious calibration and intercomparisons with the HIS flying on the same aircraft. The MAS solar channels are calibrated in the field, using a 30″ integrating sphere before and after each ER-2 deployment, as well as a 20″ integrating hemisphere shipped to the field deployment site for periodic calibrations during a mission. A comprehensive description of both the shortwave and longwave calibration procedures, signal-to-noise characteristics, and thermal vacuum characterization of the MAS can be found in King et al. (1996).

Several field campaigns are planned with the ER-2 aircraft carrying the MAS and HIS over various scenes and ecosystems. In addition to the major national and international activities outlined above, we envision the following focused and short field deployments:

- summer deployment over the ocean, mountains, and desert (based in Mountain View, CA).

A ground campaign with the ER-2 over the ARM CART site in Oklahoma would entail:

- post-launch deployment of the MAS and HIS on the ER-2 aircraft to coincide with a MODIS overflight and to collect simultaneous ground-based class-sondes, AERI (a ground-based Michelson interferometer), tower measurements of temperature and moisture at various elevations, microwave moisture measurements, lidar and radar cloud observations, and whole sky camera images.

A ground campaign with all sky cameras (from the University of Chicago, Dr. Ted Fujita) would coincide with

- winter and summer in the upper Midwest.

Comparisons with products from other platforms are also planned. Cloud masks will be compared with those from AVHRR and HIRS/2 data, ASTER and MISR (also on the AM-1 platform), and CERES. Atmospheric profiles will be compared with those from HIRS, GOES, and AIRS/AMSU/HSB (also on the PM-1 platform). Cloud properties will be intercompared with those derived from HIRS, GOES, CERES, and MISR, as well as from in situ aircraft (see below). Aerosol optical thickness retrievals from MODIS will be compared to MISR analyses as well as to AERONET measurements. Precipitable water vapor measurements will be compared to (i) radiosonde measurements over the continents, (ii) model output obtained as part of the EOS data assimilation interdisciplinary science team (Dr. Richard Rood), and (iii) periodic differential absorption lidar measurements from the ER-2 aircraft (LASE; Dr. Ed Browell). Timing, coverage and resolution will vary from one instrument to another; for example with ASTER, comparisons will be possible for selected swaths (60 km wide with 30 m resolution) that are available for different (and selected) ecosystems no more than once every 16 days.

2.2 Sampling Requirements

Comparison of MODIS radiances and products with those from other instruments should be made periodically (perhaps annually) in different seasons in daytime and nighttime conditions. We anticipate numerous opportunities, unspecified, in which scientists worldwide will intercompare MODIS-derived atmospheric, land, and ocean data products with local measurements of the geophysical property of interest. This wide-scale synthesis of data sets from scientists from Australia, Japan, China, Europe, South America, and Africa will greatly enhance the confidence that we place in the MODIS-derived products, and will, with time, aid our ability to assess the quality of the data products from a wide variety of climatic conditions and seasons. This would not be possible, nor appropriate, for the small MODIS Science Team to accomplish entirely on its own.

2.3 Measures of Success

Adjustments will be made to MODIS algorithms so that three sigma confidence will be achieved. This will take at least two years to assemble, and implement, the lessons learned from these validation assessments. As these assessments become known to the MODIS algorithm developers, adjustments will be made to the algorithms as required. We anticipate periodic reprocessing of the data set to periodically incorporate these refinements.

3.0 Pre-launch Activities

Pre-launch validation will be accomplished using MAS and AVIRIS data already gathered in various field campaigns; data that are especially valuable in combination with nearly coincident airborne in situ microphysical data as well as data from ground-based instrumentation (both remote sensing and in situ). A sampling of data sets already in-hand, along with key sensors and responsible investigators are:

Field Campaign	Principal Sensors	Responsible Team Members	Primary Purpose
ASTEX	MAS, CLS, CAR, microphysics probes	Michael King, Si-Chee Tsay, Menghua Wang	marine stratocumulus clouds over the ocean
TOGA-COARE CEPEX	MAS, CLS, microphysics probes	Paul Menzel, Steve Ackerman, Michael King, Liam Gumley	tropical cirrus clouds and multi-layer clouds over ocean regions
SCAR-A	MAS, CAR, CLS, AVIRIS, aerosol microphysics, CIMEL sunphotometers	Yoram Kaufman, Lorraine Remer, Michael King, Paul Menzel	aerosol properties in the polluted East coast region; surface bidirectional reflectance characteristics
MAST	MAS, CLS, CAR, microphysics probes	Steve Platnick, Michael King, Si-Chee Tsay	marine stratocumulus clouds over the ocean, including the effect of aerosol on clouds (ship tracks)
SCAR-C	AVIRIS, MAS, in situ aerosol probes, CIMEL sunphotometers	Yoram Kaufman, Lorraine Remer, Elaine Prins	smoke, clouds and radiation interactions resulting from forest fires in the U.S.
ARMCAS	MAS, AVIRIS	Si-Chee Tsay, Michael King, Steve Platnick, Steve Ackerman	arctic stratus clouds over sea ice; multi-layer clouds, reflectance properties of sea ice and tundra
SCAR-B	MAS, AVIRIS, CLS, CAR, microphysics, aerosol properties, CIMEL sunphotometers	Yoram Kaufman, Lorraine Remer, Michael King, Si-Chee Tsay, Elaine Prins, Paul Menzel	smoke, clouds and radiation from biomass burning in the cerrado, Pantanal, and Amazon rainforest margin
SUCCESS	MAS, CLS, HIS, AERI	Steve Ackerman, Si-Chee Tsay, Steve Platnick	mid-latitude cirrus clouds over continents

Field Campaign	***Principal Sensors***	***Responsible Team Members***	***Primary Purpose***
TARFOX	MAS, LASE, CAR, aerosol properties, CIMEL sunphotometers	Didier Tanré, Yoram Kaufman, Lorraine Remer, Si-Chee Tsay	sulfate aerosols, water vapor, and radiative forcing of aerosols in the ocean-atmosphere system

In addition, numerous data sets obtained with the CAR of the internal scattered radiation field in smoke (Kuwait oil fires), clouds (FIRE I marine stratocumulus experiment, MAST, ASTEX, ARMCAS), and many additional measurements of the bidirectional reflectance function of natural surfaces such as tundra, sea ice, oceans, smoke, cerrado, rainforests, Great Dismal Swamp, add immeasurably to a data set on the surface reflectance characteristics of natural surfaces. The analyses of these data sets are being conducted by Michael King, Si-Chee Tsay, and Jason Li.

Limited validation will also be carried out using collocated HIRS and AVHRR data sets by Paul Menzel and Steve Ackerman, focusing on surface emissivity effects. This data set has the advantage of global coverage, but the spatial scale is far removed from that of MODIS, with spectral bandwidths that are much wider and off-center from those of MODIS.

In the foreseeable future, prior to the launch of AM-1 in June 1998, we anticipate collecting the following additional data sets:

Field Campaign	***Principal Sensors***	***Responsible Team Members***	***Primary Purpose***
WINCE	MAS, HIS	Paul Menzel, Steve Ackerman, Dorothy Hall	cloud detection and properties over snow/ice covered land and lakes
FIRE III	MAS, CLS, CAR, microphysics probes, CIMEL sunphotometers	Michael King, Si-Chee Tsay, Steve Platnick, Steve Ackerman	arctic stratus clouds over sea ice, surface BRDF (tundra & ice)

The Subsonic Aircraft Contrail and Cloud Effects Special Study (SUCCESS) field experiment was conducted in April-May 1996, having the goal of determining the radiative properties of cirrus contrails, and of contrasting them with naturally occurring cirrus. To assess the radiative impact of these clouds required a well-calibrated set of radiation measurements and "ground (or in situ) truth" observations. We acquired MAS and HIS multispectral observations from the NASA ER-2 aircraft by coordinating over flights of the ER-2 with in situ aircraft and ground based measurements. The MAS and HIS measurements were employed to address the very important relationship between cirrus radiative properties and the thermodynamic environment (atmospheric temperature and moisture conditions) wherein cirrus clouds form and are maintained. The HIS provided accurate measurements of the atmospheric thermodynamical properties supporting the cirrus life cycle and the MAS measured the cirrus areal extent and radiative properties. Additional emphasis was placed on developing and validating methods of detecting upper tropospheric clouds and defining their areal extent with infrared (e.g., 13.9 mm) and near infrared (e.g., 1.88 mm) channels; these being similar to the MODIS channels and hence the MAS cirrus detection have direct relevance to the MODIS cloud mask algorithm.

Several studies have demonstrated the sensitivity of spectral radiances to cloud particle size and shape distributions. The MAS and HIS instruments provide accurate spectral measurements that can be used to assess differences in the radiative signatures between contrails and naturally occurring cirrus clouds. One difficulty in assessing the impact of high-altitude subsonic aircraft on cirrus formation and modification is the natural variability of the atmosphere and the potentially small signal of the radiative perturbation. Variations in the atmospheric spectral properties for contrail and natural cirrus conditions will be assessed with the two ER-2 instruments in conjunction with in situ and ground-based observations.

The Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX, 10-31 July 1996) campaign measured atmospheric aerosols emanating from industrial centers in North America transported over the Atlantic Ocean. Their extent, radiative properties, and transport mechanisms were studied from satellite, aircraft, and ground-based sensors. The MAS on the NASA ER-2 aircraft and the GOES Imager on GOES-8 were the primary sensors of interest to the University of Wisconsin (Paul Menzel, Steve Ackerman, Chris Moeller). The monitoring effort focused on the corridor extending from Wallops Island, Virginia to Bermuda. In situ aircraft (UK Meteorological Office C-130H, University of Washington Convair CV-580, ONR Pelican, and NASA ER-2), ground measurements (Lidar, AEROCE, AERONET), and satellite observations (AVHRR, ATSR-2, GOES) were used to measure the direct effects of tropospheric aerosols on regional radiation budgets of the cloud-free ocean-atmosphere system, while simultaneously measuring the chemical, physical, and optical properties of the predominant aerosols. The suite of measurements made during TARFOX and subsequent collaborative analyses will provide a better understanding of the impact of these aerosols over the US eastern seaboard and western Atlantic Ocean and will be used to assess the degree of closure (consistency) between aerosol radiative forcing calculations and various measurements of aerosol properties and other satellite-derived parameters. This study provided a means to validate current and future satellite remote sensing methods and products (aerosol optical thickness t_a, aerosol size distribution $n_c(r)$, and earth radiation budgets).

The Winter Cloud Experiment (WINCE January-February 1997) will investigate the difficulties in detecting clouds and estimating their properties in winter conditions. Cirrus and thin clouds over frozen tundra and lakes in the northern US and Canada will be measured with the MAS and HIS (along with the GOES-8 and AVHRR). At least one of the missions will investigate the product stability in the transition from day (visible plus infrared) to night (infrared only) and then nighttime only. In addition two ground sites in New England will be instrumented for snow and ice cover measurements and MAS/HIS flights will be made in clear sky condition (in collaboration with Dorothy Hall and George Riggs working on the MODIS snow/ice product). The field campaign will be conducted from Madison. Examples of the MAS cloud mask will be distributed to science team members so that they can determine its effect on their MODIS products.

FIRE, the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment, has previously conducted four successful field missions focused on cloud remote sensing and modeling studies as they relate to climate. FIRE Phase III will be conducted in the Arctic in two phases, phase I to be conducted over a 7 week period or longer with a serial deployment of low- to mid-level aircraft, together with a 4 week period of high-altitude ER-2 overflights. During this component of FIRE III, we anticipate utilizing the University of Washington CV-580 and, to a lesser extent, the NCAR C-130Q. Both of these aircraft will be equipped with an extensive set of PMS cloud microphysics probes, a Gerber PVM-100A liquid water content and effective radius probe, Johnson-Williams and King hot wire probes, a Nd:YAG lidar, thermodynamic state variable measurements, and selected chemistry instrumentation. In addition, the ER-2 will participate as the upper level aircraft from May 18-June 9, with the MAS, CLS, radiation measurement system for radiative fluxes, a multispectral along-track scanning radiometer, a microwave imaging radiometer. The primary sensors of interest to Goddard Space Flight Center (Michael King, Si-Chee Tsay, Steve Platnick, Robert Pincus) are the MAS on the ER-2, the CAR on the CV-580, and numerous in situ microphysics probes that will be invaluable in accessing the accuracy of cloud retrievals of the microphysical and radiative properties of Arctic stratus clouds over a bright (sea ice) surface. This valuable data set will also be of interest to the University of Wisconsin for testing the cloud mask algorithm that will be ready at-launch. The suite of measurements made during FIRE III and subsequent collaborative analyses will provide a means to validate current and future satellite remote sensing methods and products (cloud optical thickness t_c, effective radius r_e, and single scattering albedo w_0).

3.2 Operational surface networks

Data from various surface observing networks are incorporated into prelaunch validation activities, as well as selected data from the ARM site.

These are collected and archived daily at the University of Wisconsin on the Man-computer Interactive Data Access System (McIDAS), which is connected to Paul Menzel's Science Computing Facility (SCF). In addition, data from the AERONET are archived at Goddard Space Flight Center by Brent Holben and are invaluable to the aerosol pre-launch validation activities of Yoram Kaufman and Didier Tanré.

3.3 Existing Satellite Data

All of the MODIS pre-launch studies at the University of Wisconsin (Paul Menzel) rely on AVHRR, HIRS, and GOES data for field experiment support and validation. These data are archived at the University of Wisconsin and accessible on McIDAS. Additional AVHRR data collected in support of MAST, ARMCAS, and various other pre-launch validation activities are available to Goddard Space Flight Center through the archive appropriate to that experiment (Langley Research Center DAAC, Goddard Space Flight Center DAAC, or the Naval Post-Graduate School). Finally, pre-launch activities that are coordinated with Landsat-TM data sets are archived at Goddard by Yoram Kaufman.

4.0 Post-launch Activities

4.1 Planned Field Activities

In the first two years following the launch of EOS AM-1 (June 1998), we anticipate collecting data sets for the purpose of validating MODIS algorithms and data products through direct intercomparisons of MODIS data with in situ and airborne remote sensing data sets. Planned field activities that we envision participating in include:

Field Campaign	***Principal Sensors***	***Responsible Team Members***	***Primary Purpose***
FIRE III	MAS, CLS, HIS, AirMISR, RAMS, in situ microphysics	Michael King, Si-Chee Tsay, Steve Ackerman, Paul Menzel	arctic stratus clouds over sea ice
LBA	MAS, CLS, AirMISR	Michael King Si-Chee Tsay, Paul Menzel, Steve Platnick, Steve Ackerman, Yoram Kaufman, Didier Tanré	tropical clouds and biomass burning

The first field campaign after the MODIS launch will be phase II of the FIRE

III Arctic Stratus experiment described above. This component of FIRE III will be conducted August 3-28, 1998, and will coordinate the NASA ER-2 at high altitude (20 km), the NCAR C-130Q at low altitudes (1-6 km), and the SHEBA ice breaker ship, to be located near 77∞N, 135∞W in the Beaufort Sea. The ER-2 aircraft complement of sensors will include the MAS, CLS, RAMS (flux sensors), and the MISR airborne simulator, currently under development. By having MODIS, MISR, AIRS, and GLAS airborne simulators, as well as flux radiometers that will enable verification of CERES flux data sets from ER-2 altitudes as well as from the surface (SHEBA), this focused experiment should prove invaluable for intercomparison of MODIS-derived cloud mask and cloud products, CERES energy budget products, MISR multi-angle imagery, and in situ, surface and high altitude remote sensing observations.

In addition, during the near-term post-launch period, we envision participating in a much larger LBA experiment to be conducted in Brazil. Although this is not an EOS-focused experiment, Michael King, Paul Menzel, Didier Tanré and Yoram Kaufman would all be involved in data analysis and intercomparison of various data sets to be obtained in tropical South America.

4.2 New EOS-Targeted Coordinated Field Campaigns

In the first two years following the launch of EOS AM-1, we anticipate collecting the following additional data sets for the purpose of validating MODIS algorithms and data products through direct intercomparisons of MODIS data with in situ and airborne remote sensing data sets. These campaigns will be EOS-targeted campaigns of direct relevance to assuring the accuracy of MODIS-derived data products:

EOS-Targeted Field Campaign	***Principal Sensors***	***Responsible Team Members***	***Primary Purpose***
ARM overflights (Oklahoma)	MAS, HIS, CLS, AERI, surface lidar & microwave sensors	Steve Ackerman, Paul Menzel, Bo-Cai Gao, Si-Chee Tsay	mid-latitude cirrus clouds over continents, including multi-layer clouds
MOBY	MAS, HIS, CIMEL sunphotometer	Paul Menzel, Chris Moeller	cirrus clouds and atmospheric correction over the ocean
California	MAS, CLS, AirMISR	Michael King, Steve Platnick, Si-Chee Tsay	marine stratocumulus and valley fog

EOS-Targeted Field Campaign	*Principal Sensors*	*Responsible Team Members*	*Primary Purpose*
Mid-Atlantic	MAS, AirMISR, AVIRIS, in situ microphysics, CIMEL sunphotometers	Yoram Kaufman, Didier Tanré, Lorraine Remer, Bo-Cai Gao	aerosol optical thickness and size distribution, water vapor
Gulf of Mexico	MAS, HIS, surface ship, AERI	Paul Menzel, Chris Moeller	clear sky and cirrus clouds, including sediment outflow from river estuaries
California & Pacific Northwest	MAS, AirMISR, AVIRIS, CLS, CAR, in situ microphysics, CIMEL sunphotometers	Yoram Kaufman, Lorraine Remer, Elaine Prins, Didier Tanré	fires and smoke aerosol

The first EOS-targeted campaign after the MODIS launch will be coordinated with measurements taken at the ARM site in Oklahoma, probably in September 1998. The ER-2 with MAS and HIS will be deployed to synchronize with the MODIS overflight; the ARM site suite of ground-based measurements (class-sonde, AERI, tower measurements of temperature and moisture at various elevations, microwave moisture measurements, lidar and radar observations, whole ski imagers) will be collected simultaneously. These combined air and ground measurements will be used to validate MODIS radiance measurements. Results will be used to adjust the infrared calibration coefficients as necessary. In addition, the ARM ground-based measurements can be used to validate geophysical parameters as well. Lidar and radar observations of cloud boundaries over the ARM sites will be used to validate the presence of a cloud as well as its cloud top pressure altitude. Whole sky imagers are also available at the site, and can be used to compare satellite and ground-based estimates of cloud amount. Finally, optical depth measurements derived from lidar will aid in specifying the limit of thin cirrus detection in the cloud mask algorithm.

The MOBY (Marine Optical Buoy) positioned near Lanai, Hawaii will be used in December 1998 to investigate MAS and HIS infrared-derived sea surface temperatures, visible/near-infrared water-leaving radiances (using the recently added 0.47 mm channel on MAS), and radiometric calibration of the MAS measurements. The SST and water-leaving radiance data will aid in evaluating the results of several cloud mask spectral tests by providing accurate information on background radiance conditions. The effect of elevated water leaving radiances (caused by suspended materials or sub-aqueous bottom reflectance) on the cloud mask results will be investigated using MAS cloud mask results with MOBY water leaving radiances. MOBY data will also help assess temporal variability of water leaving radiance. MAS visible/near infrared calibration will be assessed by combining MOBY data with model-generated atmospheric scattered radiance. Well calibrated data are important for setting meaningful cloud mask test thresholds.

An independent ground validation campaign of MODIS cloud heights will be undertaken six months after the MODIS launch (Fall 1998) through comparisons with stereo determinations of cloud heights (using the two GOES satellites over the U. S. and the University of Chicago ground all sky cameras), aircraft reports of cirrus cloud heights (from the ACARS), and lidar estimates of cirrus heights (using the University of Wisconsin lidar). These intercomparisons will be conducted in concert with a field campaign of the MAS on the ER-2 after the MODIS launch (probably at the time of the ARM overflights described above). Validation of the MODIS cloud emissivity will be attempted through comparison with the lidar determinations. Pre-launch validations will come from cloud top property determinations with MAS data from several field campaigns which will include stereo and lidar measurements as well.

Once the MODIS is in orbit and returning regular data, we envision two focused periods of ER-2 overflights, to be coordinated with the EOS AM-1 orbit, in California (the first one over marine stratocumulus clouds located over the ocean between Monterey and San Diego in July 1999, and the second over valley fog in the central valley of California in December 1999). These experiments would entail ER-2 flights from home base in California (either Ames Research Center or Dryden Flight Research Center), and would consist, once again, of the MAS and CLS, together with coordinated underflights by the University of Washington CV-580 with its in situ microphysics probes. This data set, of special interest to Goddard Space Flight Center (Michael King, Steve Platnick, Si-Chee Tsay) would help to validate the cloud optical thickness and effective radius between MODIS and the smaller spatial resolution airborne sensors on the ER-2.

The field experiments in the Mid-Atlantic and Pacific Northwest are designed to measure two different aerosol types located in different climatic regions. Sulfate-dominated aerosol in the Mid-Atlantic, high humidity, and semi-cloudy environment, is produced from long range transport of SO_2 and aerosol and therefore represents aged aerosol. The aerosol in smoke from prescribed fires is a fresh organic aerosol with black carbon and strong coagulation downwind. These two experiments represent the range of variability of aerosol properties to be expected when dominated by submicron-sized particles. Experiments dominating by dust (such as Sahelian outbreaks from Africa) will be planned later on. In the Pacific Northwest experiment we plan to observe the relationship between aerosol emission and properties of the fires that causes these emissions. In addition to the ER-2 aircraft with the MAS, MISR airborne simulator, lidar system, and AVIRIS, we plan to collaborate with in situ measurements and ground-based characterization of both aerosol and water vapor properties. These validation campaigns are of interest to Yoram Kaufman, Didier Tanré, Lorraine Remer, and Bo-Cai Gao, and will be useful in validating both aerosol optical and microphysical properties, total column water vapor, and fires.

Finally, the Gulf of Mexico campaign that will involve the ER-2 aircraft and surface ships is similar to previous campaigns conducted by Paul Menzel and Chris Moeller. Here the focus is on characterizing the MODIS-derived sea surface temperature and sediment outflow from river estuaries, and in characterizing cirrus clouds over a well characterized ocean surface. The primary sensors of interest are the MAS and HIS from the ER-2, and a dipping-bucket sea surface temperature instrument and AERI instrument from a well-coordinated surface ship.

4.3 Other Satellite Data

MODIS retrievals will be compared to those determined from in situ radiosonde measurements, the NOAA HIRS operational retrievals, the GOES sounder operational retrievals, NCEP analysis of all available data, and retrievals from the Atmospheric Infrared Sounder (AIRS) on the EOS PM-1 platform. Total ozone will be compared to Total Ozone Mapping Spectrometer (TOMS) measurements as well as the operational NOAA ozone estimates from HIRS. In addition, MODIS aerosol retrievals will be compared to POLDER and ILAS on ADEOS. ADEOS is one of several platforms that will carry the TOMS instrument in the 1998 time period.

4.4 Measurement Needs at Calibration/Validation Sites

In order to assure that the cloud, aerosol and water vapor products are properly derived from our satellite-based data processing algorithms, it is necessary to coordinate many of the above-specified airborne campaigns with in situ cloud microphysics, aerosol sampling, and meteorological sampling. For this purpose we plan to make use of our long-standing collaboration with Prof. Peter V. Hobbs, University of Washington, and coordinate many of our cloud and aerosol campaigns from the ER-2 and AM-1 with in situ sampling from the University of Washington CV-580 aircraft.

In addition, we envision intercomparing MODIS-derived column aerosol products with AERONET, AEROCE and ARM sites, as appropriate. These are all surface networks with long-term measurements that will enable long-period assessments of our derived products through intercomparisons with these data (aerosol optical thickness, aerosol size distribution, precipitable water). Precipitable water vapor will be also validated using ground-based microwave radiometers, WMO radiosonde sites, and Raman lidar systems. Some of the AERONET sites will be equipped with lidars to measure the vertical distribution of aerosol and their optical properties (extinction coefficient and backscattering).

4.5 Needs for Instrument Development

We envision no need to further develop any airborne or in situ instruments, but rather to continually assess the performance of the MODIS Airborne Simulator and to perform regular calibration and characterization experiments, upgrading the spectrometer as required. Based on initial operational experience, we currently anticipate a number of improvements, enhancements of capability, and laboratory tests. Instrument enhancements include: (i) the addition of an onboard shortwave calibration source, to enable stability of shortwave calibration to be monitored in-flight, and (ii) the installation of a mechanical shutter to protect the optics during the descent phase of the aircraft. Laboratory measurements planned for the near future include: (i) comprehensive thermal vacuum chamber testing and analysis to enable enhanced confidence in thermal correction algorithms, (ii) measuring and characterizing the polarization sensitivity of the MAS as a function of wavelength, (iii) measuring the modulation transfer function and point spread function of the MAS, (iv) viewing a calibrated high-temperature blackbody source, and (v) characterizing the spectral response functions periodically with high spectral resolution interferometric sources. Finally, we plan to improve the stability of the 20 in integrating hemisphere that accompanies the MAS on field deployments by incorporating variable power supplies that are servo-controlled by reference detectors.

Similarly, the Cloud Absorption Radiometer and High-spectral resolution Interferometer Sounder will be upgraded or have parts replaced, as is necessary to maintain their usefulness in field validation activities.

In addition to the airborne radiometers mentioned above, there is a continuing need to develop new instruments for better measurements of the aerosol single scattering albedo, CCN spectrum, size dependent chemical composition, and phase function of ice crystals. We plan to collaborate with other groups in this regard, and not to initiate or develop this capability ourselves.

4.6 Geometric Registration Site

None are required for validating MODIS atmosphere algorithms.

4.7 Intercomparisons

Post-launch validation of the thermal infrared cloud phase product with other MODIS products will consist of close inspection of sections of data representing differing cloud regimes and surface types, including cross checks during the day mode with the visible reflection function technique of King et at. (ATBD-MOD-05) and consistency with the cloud top properties results.

Validation of the MODIS cloud products will also be done post-launch using products derived from the ASTER, CERES, and MISR sensors on the AM-1 , CERES on TRMM, and GLI on ADEOS-2.

The MODIS Cloud Mask will be compared to the ASTER Polar Cloud Mask to ensure consistent classification of polar cloud cover. The ASTER product will include a classification for each pixel poleward of 60∞N or 60∞S using a bit map with the following bit flags: unknown, ice cloud, water cloud, shadow, land, ice, wet ice, and water. The high spatial resolution of the ASTER data (30 m at nadir) will help to ensure that sub-pixel effects are properly accounted for in the MODIS data.

The MODIS Cloud Mask and Cloud Properties (cloud top pressure and temperature, effective emissivity, cloud optical thickness, thermodynamic phase, and effective radius) products will be compared to the CERES Single Satellite Footprint (SSF) and Single Satellite Gridded products that include cloud top pressure and temperature, cloud optical thickness, effective radius and phase, and cloud category (lower, lower-middle, upper-middle, high). CERES is heavily dependent on MODIS observations for cloud detection, so it will be important to ensure that the MODIS and CERES-derived cloud products are consistent.

The MODIS Cloud Mask and Cloud Properties (cloud top pressure) products will be compared to the MISR Top-of-Atmosphere/Cloud Product. The components of the MISR product that will be used are Reflecting-Level Reference Altitude (retrieved using MISR stereo imagery), Angle-by-angle cloud masks, Cloud shadow mask, and Altitude-binned cloud fraction. The MODIS and MISR Cloud Masks will be compared to ensure consistency of cloud identification, and the MISR stereo cloud heights will be compared with the MODIS cloud top heights to geometrically validate the MODIS radiometrically derived cloud height data.

We plan to compare the MODIS aerosol product with the aerosol product derived from MISR (MIS05). Using field experiments as well as AERONET and AEROCE networks, we plan to investigate the relative success of each of these techniques as a function of aerosol type, season, surface cover, and view and illumination directions. This will be an ongoing research endeavor involving Yoram Kaufman and Didier Tanré of the MODIS Team, and Tom Ackerman, Jim Conel, Ralph Kahn, John Martonchik, and Dave Diner of the MISR Team.

For atmospheric water vapor, the MODIS precipitable water product will be compared to column water vapor derived from numerous AERONET sunphotometers worldwide, as well as with precipitable water estimates derived from passive microwave measurements at the Oklahoma ARM CART site.

5.0 Implementation of Validation Results

5.1 Approach

The MODIS atmosphere algorithms for the cloud mask, cloud properties, aerosol properties, precipitable water, and atmospheric profiles will evolve in the first year after MODIS is launched in accordance with seasonal changes and validation results. Thereafter, algorithm changes will be restrained to occur once per year as needed. We anticipate assessing the performance of the MODIS algorithms initially by processing one month per season (October, January, April, July), as well as specific time periods with validation experiments of special relevance, as outlined above. After initially looking at one year's data, consistency checks, quality assurance flags, validation campaigns, as appropriate, and intercomparisons with other instruments (especially on AM-1), we will begin whole-scale reprocessing, including every month. This initial stage may take in excess of one year, during which time the MODIS calibration algorithm will likely undergo additional refinement. Continual refinement of the MODIS "operational" algorithms will largely be conducted at the Team Members SCF as well as at the Team Leader Computing Facility (TLCF), as many of the algorithms are dependent on results from other algorithms (like calibration). Only periodically (after say 1.5 years following launch), the first reprocessing at the DAAC will be initiated.

5.2 Role of EOSDIS

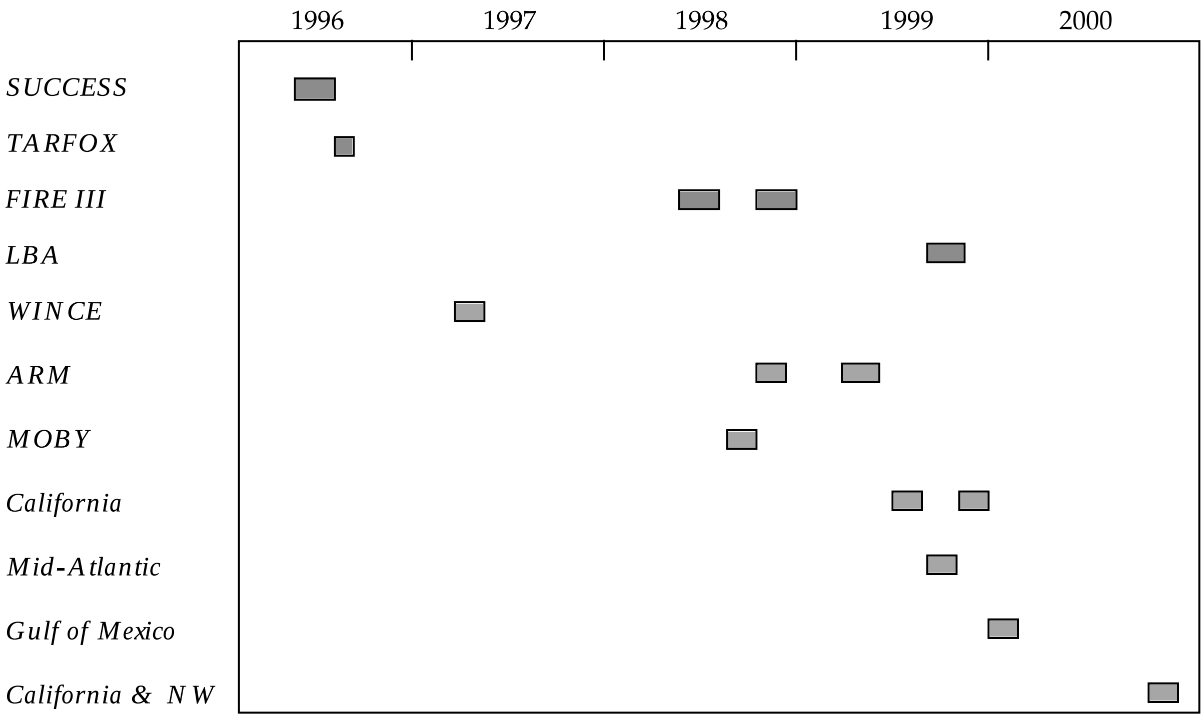
To investigate algorithm changes, past data sets (covering different seasons and ecosystems) will be necessary. We expect that these data will be archived and available through EOSDIS. The bulk of the data sets that we have thus far obtained (including CAR, MAS, and University of Washington C-131A in situ data) have been archived and are available through relevant EOS Distributed Active Archive Centers (DAACs). The specific point of data distribution for MAS data is clearly identified as part of the browse imagery archive portion of the MAS World Wide Web site (at http://ltpwww.gsfc.nasa.gov/MODIS/MAS/Home.html). Any interested investigator can thereby obtain data sets for any flight or experiment that has been processed. A Web site for CAR data will be developed in the next year.

5.3 Archival of Validation Data

The MODIS Science Team plans to gather all relevant data from various validation exercises and make these data available through EOSDIS. We anticipate that the MODIS home page on World Wide Web (at http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html) will soon establish a link to the location and availability of all MODIS-related validation data sets.

6.0 Summary

This plan represents the thought process of all MODIS atmosphere team members, associates, and close colleagues. This discipline group has considerable field campaign experience as well as experience with other satellite and surface networks of data. Putting all such validation schedules together, we obtain the following "master schedule" for MODIS atmosphere validation activities:



Additional contributions from the wider scientific community are encouraged.

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8.0 Acronyms

ACARS — ARINC (Aeronautical Radio Inc.) Communications, Addressing and Reporting System

AERI — Atmospheric Emitted Radiation Interferometer

AEROCE — Aerosol/Ocean Chemistry Experiment

AERONET — Aerosol Robotic Network

AirMISR — Airborne MISR

AIRS — Atmospheric Infrared Sounder

AMSU — Advanced Microwave Sounding Unit

ARM — Atmospheric Radiation Measurement Program

ARMCAS — Arctic Radiation Measurements in Column Atmosphere-surface System (Beaufort Sea, Alaska, June 1995)

ASTEX — Atlantic Stratocumulus Transition Experiment (Azores, June 1992)

ASTER — Advanced Spaceborne Thermal Emission and Reflection radiometer

AVHRR — Advanced Very High Resolution Radiometer

AVIRIS — Airborne Visible/Infrared Imaging Spectrometer

CAR — Cloud Absorption Radiometer

CART — Clouds and Radiation Testbed

CEPEX	Central Equatorial Pacific Experiment (Fiji, February-March 1993)
CERES	Clouds and the Earth's Radiant Energy System
CLS	Cloud Lidar System
COARE	Coupled Ocean-Atmosphere Response Experiment
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
FIRE	First ISCCP Regional Experiment (California, June-July 1987, Beaufort Sea, Alaska, April-June, August 1998)
GLAS	Geoscience Laser Altimeter System
GLI	Global Imager
GOES	Geostationary Operational Environmental Satellite
HIS	High-spectral resolution Interferometer Sounder
HIRS	High Resolution Infrared Radiation Sounder
HSB	Humidity Sounder from Brazil
ILAS	Improved Limb Atmospheric Spectrometer
ISCCP	International Satellite Cloud Climatology Project
LASE	Lidar Atmospheric Sensing Experiment
LBA	Large Scale Biosphere-Atmosphere Experiment in Amazonia
MAS	MODIS Airborne Simulator
MAST	Monterey Area Ship Tracks Experiment (Monterey and nearby Pacific Ocean, June 1994)
McIDAS	Man-computer Interactive Data Access System
MISR	Multi-angle Imaging Spectro-Radiometer
MOBY	Marine Optical Buoy
MODIS	Moderate Resolution Imaging Spectroradiometer
NAST	NPOESS Aircraft Sounding Testbed

NCAR	National Center for Atmospheric Research
NPOESS	National Polar Orbiting Environmental Satellite System
POLDER	Polarization and Directionality of Earth's Reflectances
RAMS	Radiation Measurement System (NASA Ames Research Center and Scripps Institution of Oceanography)
SCAR-A	Sulfate, Clouds and Radiation–Atlantic (Delmarva Peninsula and near-by Atlantic Ocean, July 1993)
SCAR-B	Smoke, Clouds and Radiation–Brazil (Brazil, August-September 1995)
SCAR-C	Smoke, Clouds and Radiation–California (Pacific Northwest, September 1994)
SCF	Science Computing Facility
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SHEBA	Surface Heat Budget of the Arctic Ocean
SST	Sea Surface Temperature
SUCCESS	Subsonic Aircraft Contrail and Cloud Effects Special Study (April-May 1996)
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment (Delmarva Peninsula and near-by Atlantic Ocean, July 1996)
TLCF	Team Leader Computing Facility
TM	Thematic Mapper
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
WINCE	Winter Cloud Experiment
WMO	World Meteorological Organization